PB-238 654

AN ANALYSIS OF THE CURRENT IMPACT OF PLASTIC REFUSE DISPOSAL UPON THE ENVIRONMENT

BATTELLE COLUMBUS LABORATORIES

PREPARED FOR
NATIONAL ENVIRONMENTAL RESEARCH CENTER

DECEMBER 1974

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1. REPORT NO. EPA-670/2-74-083	2. PB 238 654
4. TITLE AND SUBTITLE: An Analysis of the Current Impact of Plastic Refuse Disposal Upon the Environment	5. REPORT DATE: December 1974-Issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): D. A. Vaughan, M. Y. Anastas, and H. H. Krause	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Battelle, Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201	10. PROGRAM ELEMENT NO. 1DB063; ROAP 24ALL, Task 19 11. CONTRACT/GRANT NO. R800055
12. SPONSORING AGENCY NAME AND ADDRESS: National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
refuse*, disposal, plastics*, wastes, environmental engineering*, analyzing	environmental impact, plastic waste disposal current impact	13B

18. DISTRIBUTION STATEMENT: Release to Public	19. SECURITY CLASS *(This Report)*: Unclassified	21. NO. OF PAGES: 57
	20. SECURITY CLASS *(This page)*: Unclassified	22. PRICE: $4.25-2.25

EPA Form 2220-1 (9-73)

022131

EPA-670/2-74-083
December 1974

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NATIONAL ENVIRONMENTAL RESEARCH CENTER
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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This study represents a beginning effort toward a more scientific understanding of plastic wastes disposal and the resulting effect, if any, on the environment. In the future, the Environmental Protection Agency also plans to perform vigilant observations on man's changing needs and practices in regard to plastic waste management.

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ABSTRACT

In view of the 7-fold growth in the amount of plastic waste over the past 20 years the impact of plastic refuse disposal upon the environment has been evaluated on the basis of the major current methods of disposal, municipal incineration, landfill and litter. While weight percentage of the plastic component may tend to be used to evaluate its contribution to the environmental impact via incineration, the volume percentage of plastics is more important with respect to its contribution to landfill, both sanitary and open dump with and without burning. A useful life analysis of plastic products is described which quantifies the amounts of plastic waste by type.

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SECTION I

SUMMARY AND CONCLUSIONS

The current contribution of 5×10^6 tons/year of plastic waste to the environmental impacts of solid waste disposal was studied from two points of view. The first was related to its contribution to the environmental impact of municipal incineration while the second involved the impact of land disposal. The latter included sanitary landfilling, open dumping (with and without burning), and litter.

For incineration the impacts studied were divided into two categories: (A) incinerator operation and corrosion, and (B) air pollution impacts of plastics incineration. In regard to operation it was found that (1) while film type plastics such as bags, constituting about 1.5 percent of the refuse, may interfere with efficient refuse preparation prior to incineration, their effect was negligible, (2) the high heating value of plastics contributes to higher operating temperatures which can be beneficial in eliminating odors and efficient combustion, (3) some plastics (urea-formaldehyde resins) contribute to incinerator grate damage by corrosion, and (4) the tendency of plastics to melt before the ignition temperature is reached may cause grate plugging or hangup. In assessing the effects of plastics on incinerator corrosion, it was found that polyvinyl chloride (PVC) currently a 0.2 percent component of solid waste contributes about 20 weight percent of the total chlorine in the refuse. Since chlorides are well known corrosion agents, the chloride bearing plastics are significant contributors to the corrosion of the internal metals of incinerators. When the incinerators are fitted with heat recovery systems, the chloride from plastics may cause a 15 to 20 percent increase in tube maintenance costs due to metal wastage in heat recovery tubes. On the other hand, the chloride from plastics that collect in scrubbers contributes only modestly to the damage of their structural parts by the circulating acid waters.

Incineration of refuse was found to be a very minor (<0.2 weight percent) contributor to air pollution. In adverse weather conditions wherein dispersion of pollutants is poor, high level concentrations of particulates, carbon monoxide and hydrogen chlorides can occur. Plastics, in particular PVC, contribute 21 percent of the hydrogen chloride emitted from incinerators. This is a potential health hazard to man and can be detrimental to plants and animals. Furthermore the damage caused to man-made structures exposed to relatively small concentrations of HCl for long periods of time needs to be investigated.

A number of impacts of land disposal of plastics were considered in this study. These were the effects of disposal on the air, water, and land environments in addition to estimation of the level of noise generation at the land disposal sites. The above impacts were in turn qualitatively related to (1) aesthetic impacts, (2) ecological impacts, and (3) human interest factors (health and socioeconomic). For land disposal, the volume of plastic waste becomes more important than its weight. It is shown that the 2.6 weight percent plastic component contributes 5 volume percent which results in a corresponding effect upon land disposal methods, litter, and the above environmental parameters. Burning of open dumps, which occurs with approximately 27 percent (52.5×10^6 tons/year) of the total solid waste reduces the volumetric contribution of the plastic waste and gravimetric quantities of plastic are used in evaluating its impact.

It was estimated that the 1.37×10^6 tons of plastic waste would give a total pollutant emission which is 24 percent of the total emissions obtained from incineration of 17×10^6 tons of solid waste. However, the hydrocarbons and hydrogen chloride emissions were 2.0 and 1.3 times the corresponding pollutants obtained from incinerators. Although the emissions are negligible on a nationwide basis, they can be serious in areas surrounding the site especially under adverse weather conditions. Smoke and particulate matter together with odors are highly unaesthetic and produce adverse reaction toward utilization of land adjacent to the site.

In sanitary landfills the putrescible components of refuse decompose anaerobically giving off gases consisting of about 65 percent carbon dioxide and 29 percent methane. It was estimated that the presence of plastics contributes indirectly to the generation of these gases at annual rates of 13,000 and 2,200 tons, respectively. While the methane is not toxic it may, without proper ventilation, migrate in the soil and cause explosions and fires in neighboring structures. It may also cause the displacement of oxygen from the root zone of plants in the vicinity of the disposal site. About 600 tons of carbon dioxide per year may dissolve in ground waters under the landfill site. This may cause an increase in the hardness of those waters and a general degradation in their quality.

The land disposal of plastics may indirectly cause some water pollution that is detrimental to aquatic life in some parts of neighboring natural bodies of water. The pollutant loading for open dumping and sanitary landfilling was estimated at about 28 and 6 percent respectively of the pollution potential of raw untreated domestic sewage from a city of one million.

The land required for disposal of plastics represents a total annual nationwide land commitment of 52 and 950 acres for sanitary landfilling and open dumping, respectively. While this is indeed a comparatively small area it nonetheless contributes to the aesthetic, ecological, and human health impacts of encroachment of dumping sites upon the wilderness.

Inasmuch as the noise levels in the neighborhood of dumping and landfill sites were not found to be hazardous to human health and well being, the contribution of plastics is considered insignificant.

SECTION II

INTRODUCTION

Public opinion regarding volume reduction of municipal refuse (mainly from household and commercial sources) has changed drastically over the past half century from the nostalgia of bonfires in the early 1900's to the irritation created by a neighbor's outdoor grill in the 60's. Because of the changing public opinion and the increasing concentration of solid waste with the growth of urban living, local authorities became responsible for collection and disposal of solid waste generated by households and many commercial establishments. Large quantities of refuse were deposited in isolated areas where fires were set or accidentally started to reduce the volume. Material of economic value was frequently extracted from these dumps by scavengers. It is estimated that 192 million tons of municipal refuse were collected and disposed of in 1973. The means of disposal were by (1) incineration (9 percent), (2) sanitary landfill (13 percent), (3) open dumping without burning (51 percent), and (4) open dumping with burning (27 percent). Industries, in general, dispose of their own product-oriented refuse.

Municipal refuse includes a variety of plastic components which originate from the disposal of containers, molded and extruded objects and films made from those materials. Because of their versatile properties and relative low cost and ease of fabrication, plastics have found many applications in such areas as packaging, building and construction and manufacture of appliances.

The plastics content in municipal refuse has been steadily increasing since 1940. Because of such properties as nonbiodegradability, low bulk density, resistance to compaction and high chlorine content in the polyvinyl chloride component (giving rise to corrosive and toxic emissions

of HCl in municipal incinerators), they assumed significance in solid waste management and disposal. It is thus important to know the extent of their contribution to the environmental impacts of solid waste. Although environmentally acceptable methods of disposal of municipal solid waste are being pursued, the present investigation is aimed at determining the environmental impacts of plastics disposal by various means currently employed.

SECTION III

AMOUNTS AND COMPOSITION OF MUNICIPAL SOLID WASTE

Municipal solid waste consists mainly of refuse collected from residential, commercial, and to a small extent, industrial sources. In a 1968 study of municipal refuse collection in New York City[12] it was projected that in 1975 the various sources mentioned above will contribute 53.4, 37.5, and 9.3 weight percent, respectively.

The characteristics of municipal solid waste are not uniform and the quantities (or percentages) of its various components are dependent on many factors. Among others, location (urban and rural), personal income levels, and population density are the major influences in the rate of generation and characteristics of the refuse.[13] Table 1 gives those characteristics as reported in the sources given. According to published information[13] the daily generation of municipal refuse in 1968 was 5.72 and 3.93 pounds per capita per day for urban and rural areas, respectively. This roughly corresponds to about 200 millions tons per year.

A more accurate determination of the total municipal solid waste and its characteristics will be presented later in this section.

The density of municipal solid waste in the home refuse container has been decreasing steadily over the past five decades. While this density may presently vary between 100 and 1500 pounds per cubic yard there has been a drop in the average density from 1100 to 160 pounds per cubic yard.[6] Municipal refuse is usually collected and hauled in compactor trucks capable of a 2 to 3 compaction ratio. This will increase the density to at least 320 pounds per cubic yard. It has been reported[8] that sanitary landfilling of refuse could increase this density to 900 pounds per cubic yard. The density of refuse in open dumps is reportedly[8] 50 percent of that in sanitary landfills or about 450 pounds per cubic yard.

Although it is desirable to know the volume percentages of the various components of refuse in order to determine the specific impact of a component under consideration, there seems to be a paucity of data in this regard. EPA[17] has given volume and weight percentages for the components listed in Table 2.

TABLE 1. COMPOSITION OF MUNICIPAL SOLID WASTE. (WEIGHT PERCENT)

	Battelle[e]	Ref 15	Ref 13[c]	Ref 16	Ref 17
Paper	45	53.2	33.0	46.0	58.8
Yard and Dirt	15	11.5	0.4	10.0	7.6
Garbage[b] - Food Waste	11	4.3	26.4	12.0	9.2
Glass and Ceramics	10	6.2	16.1	10.0	8.5
Metallics	9	7.9	10.7	8.0	7.6
Wood	3	2.0	0.3	7.0	2.5
Plastics, Rubber and Leather	2[a]	6.2	6.8	4.0[d]	1.7
Textiles, Rags	2	4.3	6.3	3.0	.9
Miscellaneous	3	4.4[b]	--	--	3.3
Total	100.0	100.0	100.0	100.0	100.0

(a) This is for plastics only. Does not include Rubber and Leather.
(b) Combination of so-called "diapers" and "fines".
(c) Composition of domestic refuse in low-income public, high-rise housing.
(d) Includes 2 percent for "plastic film" and 2 percent for "leather, molded plastics,[and] rubber".
(e) An average from numerous studies.

TABLE 2. VOLUME AND WEIGHT-PERCENTAGES OF SELECTED COMPONENTS IN MUNICIPAL SOLID WASTE[a]

Component	Weight Percent	Volume Percent
Paper	62.0	75.5
Garbage	18.7	6.8
Metals	9.1	12.9
Minerals (Ash, Brick, etc.)	1.7	0.5
Glass	8.5	4.3
Total	100.0	100.0

(a) Source: Ref 17

In a recent report[13] the volume and weight percentages of a number of components of municipal refuse resulting from a high-rise, public housing building were given. These are reported in Table 3.

TABLE 3. WEIGHT AND VOLUME PERCENTAGES OF SOME COMPONENTS IN MUNICIPAL SOLID WASTE

Component	Weight Percent	Volume Percent
Paper	33.0	62.6
Wood	0.4	0.15
Plastic, Leather, and Rubber	6.8	9.1
Textiles	6.4	5.1
Glass	16.1	5.3
Metal	10.7	9.1
Garbage	26.3	8.6
Minerals	0.3	0.1
Total	100.0	100.0

Table 4 presents Battelle estimates of the weight percentages of the various components together with their amounts in the refuse on an annual basis.

TABLE 4. AMOUNTS AND PERCENTAGES OF COMPONENTS IN MUNICIPAL SOLID WASTE

Components	Weight Percent	Millions of tons Collected per year
Paper	45	86.5
Yard and Dirt	15	28.8
Garbage	11	21.2
Glass, Brick, etc.	10	19.2
Metal	9	17.3
Wood	3	5.7
Plastic	2	3.8
Textile	2	3.8
Miscellaneous	3	5.7
Total	100	192.0

PLASTICS IN MUNICIPAL SOLID WASTE

The weight percentage of plastics in municipal solid waste has been steadily increasing over the past three decades. These percentages were zero (or unknown), 0.4, and 1.5 for the years 1939, 1953, and 1968, respectively.[8] The increase in the use of plastics occurred mainly because of their relative light weight and low cost as packaging materials and containers. Between 1958 and 1974 packaging uses of plastics rose from 0.1 to 4.7 billion pounds.[12] This amounts to about 46 percent of the estimated plastics in the refuse.

As indicated above, the total plastics content found in solid waste by sorting is reported to be approximately 2 percent or 3.8×10^6 tons/year, but this amount may vary by as much as a factor of 2 (1 - 4 percent) from one time or place to another. On a national basis it is possible from well established plastic production figures and estimates of useful life of products, to calculate the total amount of plastics discarded into the solid waste stream. As the useful life can be estimated for nearly all products in terms of years (1, 5, 10, 20, or 50), it would appear that the amount of any product entering the solid waste stream annually will be related to its useful life and will vary from 100 percent of the annual production to as little as 2 percent. For the purpose of evaluating the quantity of plastic waste, estimates were made of the useful life of the various plastic products for which the total market volume was published.[14] The life estimates for individual products were based upon broad categories as shown in Table 5 with some exceptions where the individual product does not fit the general case.

TABLE 5 . END USES AND LIFE EXPECTANCIES OF PLASTICS

End Use	Approximate Life Years
Packaging	1
Transportation	5
Furniture/Housewares	10
Electrical/Electronics	10
Appliances	10
Fixture	20
Building/Construction	50
Export	Omitted

From recently published data[14] on the amounts of the various plastics employed in the end uses given in Table 5 and from the useful lives given therein, estimates of the magnitude of plastics in the municipal solid waste were made. As a result of this analysis, the total quantity of plastic waste generated in 1973 was calculated to be 5.05×10^6 tons. The above quantity of plastic waste contributes 2.62 percent of the total refuse. This is consistent with results reported by various investigators from data obtained by sorting techniques. The advantage of the useful life approach, however, is that the quantity of each type of plastic is obtainable, as shown in Table 6, based upon the life expectancy for the eight categories given in Table 5.

TABLE 6. MARKET AND WASTE VOLUME BY PLASTIC TYPE FOR 1973

Type of Plastic	Total Volume, 10^5 Tons		Percentage of Plastic Waste in Total		
	Market	Waste	by Type	Plastic Waste	Solid Waste
Ethylene	43.10	28.25	65.6	56.1	1.470
Styrene	26.50	10.10	38.1	20.0	.525
Vinyl Chloride	23.85	4.27	17.9	8.5	.212
Polyesters	11.85	1.10	9.2	2.2	.057
Propylene	10.78	2.98	27.5	5.9	.155
Phenolics	7.18	.98	13.6	1.9	.051
Urethane	6.52	.97	14.8	1.9	.051
Urea-Melamine	4.99	.54	10.5	1.1	.028
Acrylics	2.56	.33	12.7	.65	.017
Epoxy	1.09	.95	23.3	.50	.013
Nylon	.88	.14	16.5	.29	.007
Cellulosic	.85	.49	58.5	.98	.026
Acetate	.34	.08	25.0	.02	.004
Carbonates	.34	.05	14.3	.01	.003
Total	140.83	50.53	34.4	100.05	2.619

Although the weight percentage of plastics in the solid waste stream is small (2.6 percent) their end uses (in packaging for example) will tend to increase their volume percentage. While the average density of plastics used in packaging is 71 lb/ft^3[12] an uncompacted bottle will have a bulk density of only 1-2 lb/ft^3. Unfortunately, as mentioned earlier, data on volume percentages for components of solid waste are meager, and an attempt has been made to arrive at a reasonable volume percentage for plastics in the solid waste. This involved: (1) assuming a given volume percent of plastic in the refuse and calculating the corresponding bulk density, and (2) estimating the bulk density of plastic articles that appear in the refuse. The values used for comparison are given in Table 7. An inspection of the bulk densities calculated for the various examples chosen, suggests that the range of the volume percentage of plastics in the refuse may range from 2 to 10 percent. However, a value of about 5 percent appears to be valid because the estimated bulk density of molded plastics bottles (2.77 pounds per cubic foot) corresponds to a volume percent between 4 and 5. Since bottles are generally known to resist compaction (in comparison to film, tubes, etc.) it will be assumed that their bulk density is representative of plastics. This will represent an upper limit to the volumetric contribution from plastics to uncompacted refuse. The use of shredding will lower the volumetric contribution of the plastics.

A significant factor in the volumetric contribution of plastics to solid waste is their reported resistance to compaction[8,12]. In this regard a qualitative description of the behavior of plastics under various conditions of compaction may be cited from page I-9, Ref. 8.

> "The bulk of the plastics entering the solid waste stream originate from the packaging industry where they are used as films, overwraps, bottles, jars, tubes and other forms of containers. In general, they are not brittle and therefore do not readily break upon impact to smaller fragments. Even under moderately heavy loads, they will not easily disintegrate, but deform and tend to return to their original shape when the load is removed. In compaction or in a sanitary landfill, therefore, plastics tend to confer a somewhat lower finished density."

TABLE 7. ASSUMED VOLUME PERCENTAGES VERSUS CORRESPONDING BULK DENSITIES FOR PLASTICS IN REFUSE(a)

Volume, percent	Average Bulk Density, lb/ft^3	Comments
1	11.8	
2	5.5	Corresponds to average bulk density of refuse
3	3.9	
4	3.0(b)	Approximately the bulk density of all blow molded plastic bottles produced in 1966
5	2.4	
7	1.6	Bulk density of a 1 gallon polyethylene bottle
10	1.2	Low end of the range for plastic foams

(a) Assuming an average refuse density of 160 lb per cu yd and a plastics content of 2 percent by weight.

(b) Table 53, p 85, Reference 12, shows that the number of blow molded bottles, produced in 1966 were 3,112 million units weighing 304 million pounds. An average capacity of 1 liter (about 32 fl oz) was assumed giving a bulk density of 2.77 lb per cu ft.

On that basis it is expected that the volumetric percentage of plastics in dumps, landfills and compactor trucks will be higher than that in the compacted state. While some compaction will undoubtedly take place it is not presently known to what extent. The properties of viscoelasticity and impact resistance in addition to the superior compactibility of metallic and glass objects[12] in the refuse will, perhaps, cause some articles made from plastic to contribute to a higher volume percentage in the compacted state.

Despite the resistance of plastics to compaction relative to other components of solid wastes it will be assumed that the estimated volumetric contribution of plastics to solid waste will be retained at 5 percent under all conditions. This means that in a landfill situation, for example, the volume percentage will also apply.

METHODS OF DISPOSAL OF MUNICIPAL SOLID WASTE

Municipal solid waste is disposed of by three main methods. These are (1) incineration, (2) sanitary landfill, and (3) open dumping. The latter two categories constitute schemes for land disposal. The significant reduction in the volume of solid waste by incineration was recognized and many municipalities constructed furnaces for disposal by this method. As a result of the increased concentration of refuse at local sites, the problems associated with disposal of solid waste by incineration became more evident in terms of gaseous and particulate emissions, scenic blights, health and accident hazards, depreciated land values, and public nuisances. Hence, Federal air-pollution regulations were enacted and state or local controls reduced significantly the open burning of refuse with a resulting growth in the number (322) of municipal incinerators constructed. However, since 1967 the number of operating incinerators has declined[30] to approximately 195 because of obsolescence, emission control regulations and repair or construction costs. Furthermore, over 95 percent of the operating municipal incinerators have incorporated emission-control systems in the off-gas chambers or stacks. Unfortunately

corrosion is a major problem in these emission-control systems. Also, corrosion has been a major deterrent to the installation of heat-recovery systems in municipal incinerators.

Incinerators, which do not incorporate emission controls or heat-recovery systems, are in general constructed of refractory materials resistant to attack by refuse combustion products, but may be damaged by overheating. Because of differences in the corrosion behavior of various incinerators it is important to separate them into groups having different corrosion problems in order to establish their capacity and to estimate the volume processed in the different systems:

TABLE 8. DISTRIBUTION OF REFUSE INCINERATORS BY TYPE AND NUMBER [31]

Type[a]	Number	Capacity T/Day	Estimate of Volume Processed[b] T/Yr
I	8	700	0.17×10^6
II	144	48,000	11.63×10^6
III	43	21,500	5.20×10^6
Total	195	70,500	17.00×10^6

(a) I = No Emission control or heat recovery, II = Emission Control, III = Heat Recovery and Emission Control.

(b) Estimate made at 2/3 capacity to correct for downtime and less than 24 hr/day operations.

This grouping is useful for evaluating the impact on the environment by incineration of solid waste and the contribution of plastic waste to the total impact. Based upon the above tabulation, the total amount of solid waste processed by municipal incinerators is of the order of 17×10^6 Tons/Year or approximately 8.83 percent of the nation's total household and commercial solid waste stream.

Thus, the bulk of the municipal solid waste collected (91 percent) is disposed of by (1) landfill, (2) sanitary landfill, and (3) open dumping. It is not precisely known what percentage of the total solid waste is disposed of by each method. Warner et al.[8] mentioned that in 1966, "79 percent of all U.S. cities with population over 25,000 utilized landfill with almost 81 percent of the solid waste in these communities disposed of in this manner". They further stated that only 6 percent of the 12,000 U.S. solid waste land disposal sites were sanitary (or sanitary landfills). Black[1] stated that only 5 percent of the 14,000 authorized land disposal sites were sanitary landfills. The rest, he said, were essentially open dumps with which are associated such problems as air pollution, public health hazards and unsightliness. According to Black[1] there are thousands of unauthorized open dumps which are used for disposal part of the time.

According to data obtained from EPA[17] it was estimated that of the 175 million tons of municipal refuse that is not incinerated annually, 25 million tons were landfilled (presumably in a sanitary fashion), 52.5 million tons were open dumped and burned and 97.5 million tons were open dumped without burning.

SECTION IV

DISPOSAL OF PLASTICS IN REFUSE BY INCINERATION

The incineration of plastics in the refuse results in a number of impacts both on the incineration equipment used and on the environment. The equipment-related impacts are those pertaining to effects of plastics on incinerator operation and corrosion of internals thereof. The environmental impacts discussed will pertain mainly to the air pollution by the stack effluent.

Equipment-Related Impacts

Effects on Incinerator Operation

Because of the large number of variations in incinerator design and methods of operation that are not, in general, directed towards the specific problems associated with plastics, this section is limited to areas where the plastic component is known to affect operation. These areas include preparation of refuse, feeding the furnace, combustion temperature, and residue.

Although plastic bags may be beneficial in the storage and handling of bulk refuse, they present difficulties where refuse is sized for extracting recycleable materials or for conveying into the furnace. Bags and other film-type plastics contribute over 45 percent of the total plastic waste, and over 1.4 percent of the total solid waste which, along with textiles, another 1.2 percent, becomes 2.6 percent of the total solid waste that is difficult to shred. At present, however, there are only a few incinerators that process all the refuse and, thus, these materials have only a small adverse effect upon incinerator operation. As resource-recovery programs increase, the difficulties in refuse preparation for incineration can be expected to increase, particularly for the plastic and textile materials where automated handling and furnace-feeding devices are employed.

The combustion of refuse is as variable as is its components. One of the major advantages of the municipal incinerators is the higher operating temperatures which destroy the offensive odors of open burning. In this respect, plastics with their higher heat value contribute constructively to incinerator operation. Furthermore, the ash content of most plastics is lower than that of paper products and thus contributes less to the incinerator residue. Although the plastics provide some benefits to incinerator operation, they have a tendency to melt before the ignition temperature is attained. Kaiser[32] reported some slight grate damage when PVC was added to the refuse. Heimburg[33] found that with the exception of PVC, plastics burned under optimum conditions had little or no effect upon the incinerator. However, corrosive conditions did occur when urea-formaldehyde was burned at low (1200 F) temperature. With the exception of minor grate corrosion and/or grate hangup by melting of plastics, the combustion of refuse in incinerators is not likely to be adversely affected by the plastic component, and some benefits may be derived.

Effects on Incinerator Metal Components

Several components of incinerators are subjected to the corrosive environment produced by refuse combustion. Grate design and operator attention have overcome some of the problems in the combustion chamber. However, heat recovery and air pollution control equipment is subjected to the hot gases and fly-ash particles the latter of which must be extracted to meet air-quality regulations. It has been established[34-37] that the high chloride content of incinerator flue gases and particulates is the major factor contributing to the corrosion of this equipment. Unfortunately chemical analysis for chlorides in the "as-received" refuse has not been a common practice, but its presence has been verified through analysis of fly-ash, tube deposits, residue, and HCl content of the furnace and off gases. Several analyses[37] of refuse show the chlorine content to be 0.50 percent while the ash residue contains 0.014 percent chloride and the gas contains 200-300 ppm HCl. The chloride content of tube deposits[38] has varied with tube temperature from 8 percent on tubes operating at 400 F to approximately

0.5 percent on tubes operating at 1200 F. Particulates collected with stack gases were found to contain as much as 28 weight percent chloride; the HCl content of stack gas varies from 50-300 ppm.

The source of chlorine in refuse has been attributed to garbage, yard, paper, and plastic wastes. In the case of plastic, PVC is the major contributor of chlorine but other plastics may contain the species. As shown previously, the amount of PVC is estimated to be 0.2 percent of the total waste. Hence, PVC contributes approximately 0.1 percent chlorine to the refuse. Thus, nearly 20 percent of the chlorine in solid waste is introduced by a 0.2 percent component. Chlorides are well known corrosion agents and the magnitude of chloride corrosion is frequently proportional to chloride concentration where other environmental conditions and exposed materials are constant.

Effects on Heat Recovery Systems

In the case of heat recovery boiler tubes it has been demonstrated[38] that metal wastage decreases to essentially that of air oxidation when the chloride content of the deposit is reduced to less than 0.1 percent chloride. This would indicate that of the order of 20 percent of the fireside metal wastage is caused by the plastic component of refuse. However, this behavior is specific to refuse combustion product environments which are low in sulfur. On the other hand, it has been shown[38] that an addition of sulfur to refuse prevents chloride deposition on tube materials with a marked reduction in metal wastage.

Fireside metal wastage resulting from chloride attack can be expected in steam generating incinerators which cover approximately 20 percent (43/195)[31] of the operating incinerators. These incinerators dispose of 30 percent of the incinerated wastes but only 2.7 percent of the total household and commercial waste. At present the effect of the plastic component of refuse on the operation of incinerators with heat-recovery systems is to increase tube maintenance cost by 15-20 percent over that to be expected if plastic-free refuse was used as fuel.

Effects on Pollution-Control Equipment

A much larger percentage (95 percent - 187/195)[38] of the incinerators have air-pollution equipment that is exposed to the high chloride environment resulting from refuse combustion. Over 95 percent of the incinerators are equipped with some type of flue gas cleaning equipment to reduce particulate emissions. Some gaseous pollutants are absorbed in the water sprays and gas scrubbers. As a result, the cleansing action of the air-pollution-control equipment collects large quantities of water-soluble compounds and traps many of the insoluble particles consisting of combustion products and unburned material. Because of the high chloride content of the combustion products, the cooling water that contacts the flue gas contains large quantities of chlorine and is very corrosive to structural metals. Furthermore, the waters become acid by the absorption of HCl, SO_2, and SO_3 from the flue gas and attack concrete support structures and clarifier tanks. Typical characteristics of the scrubber water and the change of those characteristics with time are presented in Table 9 and Figure 1, respectively.

The impact of plastic waste upon this equipment is not as well defined as in the case of the fireside metal wastage. In the absence of the plastic component of refuse, the chlorine or chloride content of flue gases would be sufficient to cause deterioration of materials employed in air-pollution-control equipment. Hence it is concluded that the disposal of plastic waste by incineration does not add noticeably to the already existing corrosion problems associated with air-pollution control. It is important to note that the application of organic coatings to this equipment has provided corrosion protection of structural materials.

AIR POLLUTION IMPACTS

The total air pollution resulting from the operation of municipal incinerators in the United States is small compared to the contributions from all other sources. Calculations based on data from recent EPA publications[29,30] show that the incinerator contribution to the major

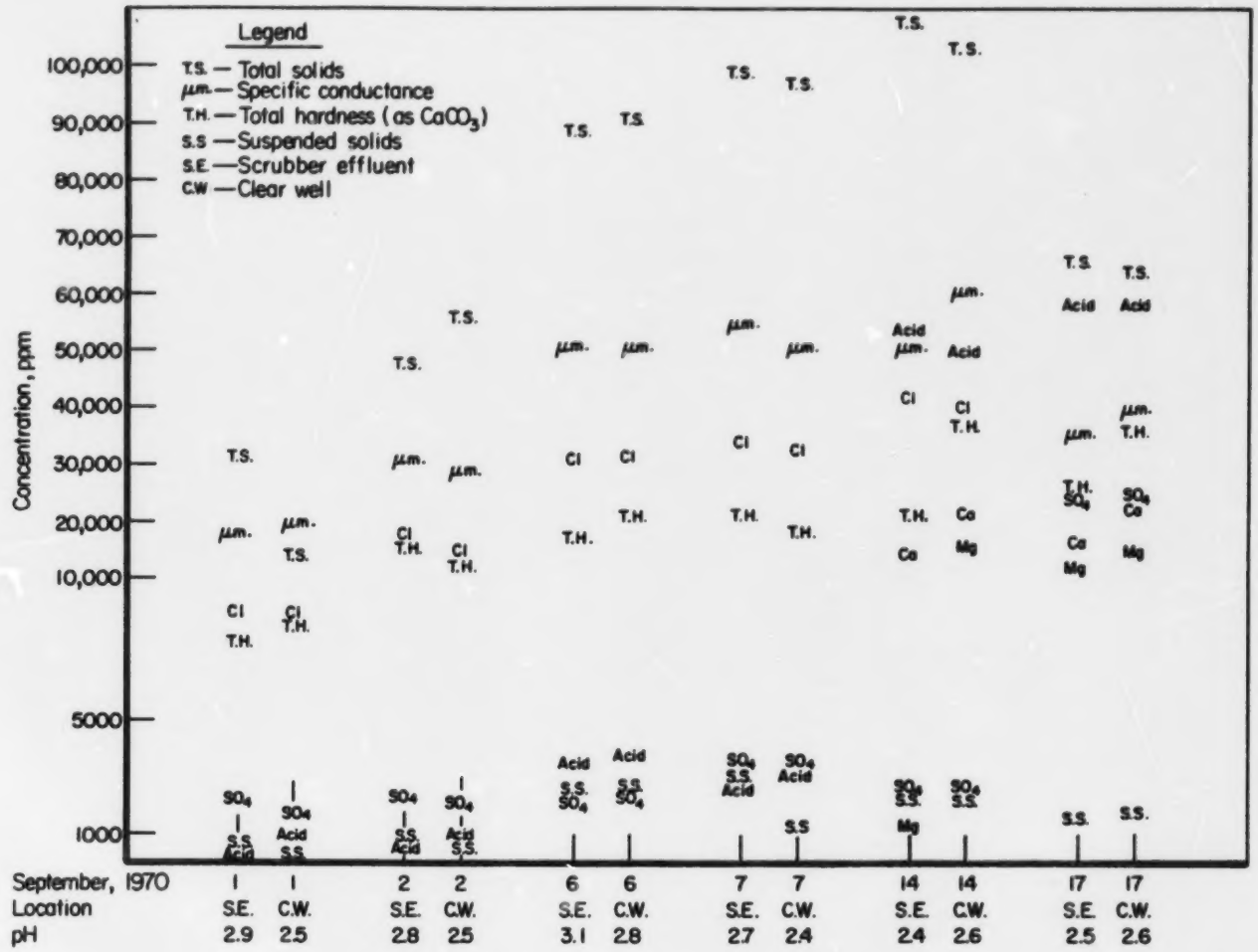

FIGURE 1. CHANGE IN COMPOSITION OF SCRUBBER WATER DURING CONTINUOUS RECIRCULATION

These data were obtained at the South Montgomery County Ohio Incinerator

TABLE 9. SCRUBBER WATER COMPOSITION[34]

Measurement	Date			
	8/31/71	10/8/71	11/2/71	12/8/71[a]
Total hardness as $CaCO_3$, ppm	2330	2760	6250	272
Calcium as Ca, ppm	568	784	1704	71
Magnesium as Mg, ppm	262	230	573	27
Sulfate as SO_4, ppm	1261	1308	1933	231
Chloride as Cl, ppm	2355	2355	1610	183
Specific conductance μmho/cm	7499	7639	11,160	833
Total solids, ppm	5916	5900	11,386	732
Suspended solids, ppm	114	14	10	114
Total acidity as $CaCO_3$, ppm	402	388	352	68
pH	4-4	4-3	5-1	4-0

(a) On this date the scrubber water was not being recirculated.

air pollutant categories amounts to about 0.2 percent of the total:

Category	Total Emissions, tons/yr	Incinerator Emissions tons/yr	Percent of Total
Particulates	26,200,000	127,300	0.486
Sulfur oxides	34,100,000	12,670	0.037
Carbon monoxide	149,000,000	291,700	0.196
Hydrocarbons	34,900,000	12,670	0.036
Nitrogen oxides	22,800,000	16,780	0.074
Total	267,000,000	461,120	0.173

In addition there are HCl emissions from incinerators, but these are not at present under regulation, so there is no nationwide data base for comparison. The total incinerator HCl emissions have been estimated at 50,200 tons per year[30], which would increase the overall incinerator emissions by 11 percent. The plastic content of the refuse is responsible for only a portion of these overall incinerator emissions of pollutants.

Emission Factors

In order to determine the extent to which the plastics contribute to the incinerator emissions, it is necessary to have available emission factors for the various components. Unless an incinerator is operated very badly, the plastics will burn sufficiently so that a negligible amount of the 14.9 lb/ton of filterable particulates emitted can be attributed to the plastic component of the refuse. Boettner[4] presented data on the major plastic components of refuse that show no residual ash, that would produce particulates, during combustion of polyethylene, polystyrene and major sources of PVC which constitute over 80 percent of the plastic wastes.

Pollutant	Incinerator Emission Factor, lb/ton
Carbon monoxide	35.0
Particulates	14.9
Nitrogen oxides (as NO_2)	3.0
Sulfur oxides (as SO_2)	2.5
Hydrocarbons (as CH_4)	1.5

Because it has not been under regulation as yet, HCl is not included in the list. However, Achinger and Baker[20] compiled an emission factor of 6 pounds per ton. Recent data on HCl were obtained by the Battelle-Columbus Laboratories at the Harrisburg, Pennsylvania, incinerator[39]. An average of 77.8 pounds per hour of HCl was found in a series of 14 measurements taken on several different days. During this time the refuse-burning rate averaged 15.35 tons per hour. Based on these results, the emission factor for HCl would be 5.1 pounds per ton. Consequently, a value of 5 to 6 pounds per ton appears to be a currently valid emission factor range to use for HCl, but with enforced regulations and effective scrubbing systems it may be lowered.

Impact of Plastics on HCl Emissions

The unique contribution of plastics to air pollution by incinerators results from the HCl produced by combustion of polyvinyl chloride (PVC). It has been shown by Boettner and his associates[4] that all of the chlorine is released from the PVC on combustion, and appears as HCl. On the basis that 0.212 percent of solid waste is PVC, and taking the total solid waste incinerated as 17×10^6 tons/yr there would be 36,000 tons/yr of PVC burned. This would produce 21,000 tons/yr of HCl.

Other sources of HCl are present in the solid waste, as there is chloride in the plant and food waste, in addition to that which occurs as inorganic salts. The formation of HCl from organic sources would take place readily during incineration. To form it from the inorganic compounds requires volatilization and reaction with incinerator flue gases such as SO_2 and CO_2. That these reactions occur is evidenced by the chemical changes observed in the incinerator deposits, where chlorides are converted to sulfates as exposure time increases.[34] The total HCl emitted by incineration amounts to 46,750 tons/yr if the emission factor of 5.5 lb/ton is used which accounts for 55 percent of the chlorine in the refuse. On this basis the amount of HCl emitted (53 percent of that produced) from the PVC is 21.3 percent of the total emitted. However, the HCl emissions from incinerators would be reduced substantially by the use of water scrubbers. Data from the South Montgomery

County Incinerator, Dayton, Ohio,[34] shows the buildup of chloride in the scrubber water as a result of the absorption of HCl (Table 9 and Figure 1). It was estimated that about 500 lbs/day of HCl were being absorbed in the scrubber water. No measurements were available on the amount being emitted from these stacks.

It is evident from the above that the amount of HCl from plastics is but a small part of the millions of tons of air pollutants produced annually in the United States. It has been claimed that much more HCl is emitted to the atmosphere from coal-burning power plants than from municipal incinerators.[40] However, there could be an air pollution problem in the immediate vicinity of an incinerator as a result of the HCl emission. This might occur if the dispersal of the stack gases were such as to cause the ambient concentration of HCl to exceed the 5 ppm level designated as the allowable limit for health.[41]

Impact of Plastics on CO Emissions

Inasmuch as all plastics contain considerable carbon, they are potential contributors to the carbon monoxide emissions from the incinerators. If the CO emission factor of 35 lb/ton is used for the plastics, on the assumption that its contribution is proportional to the amount of each type of plastic in the waste, the values shown in Table 10 are obtained. The total contribution of 7809 tons/yr of CO is a negligible amount of the 149,000,000 tons of CO emitted in the United States at the present time.

Impact of Plastics on HC Emissions

Since the chemical structure of plastics is based on carbon-hydrogen compounds as starting points, the possibility of some hydrocarbons surviving the combustion process is good. Hence it may be assumed that hydrocarbons will be produced in proportion to the amount of plastic in the refuse. On that basis, the hydrocarbon emission factor of 1.5 lb/ton was applied to obtain the values found in Table 10. The

total of 334 tons/yr is insignificant compared to the United States total of 34,900,000 tons/yr from all sources.

TABLE 10. CARBON MONOXIDE AND HYDROCARBON EMISSIONS ATTRIBUTABLE TO INCINERATION OF PLASTICS

Type of Plastic	Percent of Total Solid Waste	Carbon Monoxide, tons/yr	Hydrocarbons, tons/yr
Ethylene	1.470	4375	187.2
Styrene	0.525	1565	66.8
Vinyl Chloride	0.212	630	27.0
Polyesters	0.057	170	7.3
Propylene	0.155	461	19.7
Phenolics	0.051	152	6.5
Urethane	0.051	152	6.5
Urea-Melamine	0.028	94	3.6
Acrylics	0.017	51	2.2
Epoxy	0.013	39	1.7
Nylon	0.007	21	.9
Cellulosic	0.026	78	3.3
Acetate	0.004	12	.5
Carbonates	0.003	9	.4
Total		7809	333.6

Impact of Plastics on NO_x Emissions

Only the few nitrogen-containing plastics would be involved in contributing to the nitrogen-oxide emissions. These are among the less-used plastics, and in Table 10 include urethanes, urea-melamine, and nylon materials. It probably would not be truly representative of the situation to use the nitrogen oxide emission factor of 3 lb/ton of refuse for these plastics, because they contain a higher percentage of nitrogen than the general refuse. If this value were to be used, the nitrogen oxide emissions would be:

Plastic	NO_x Emission, tons/yr
Urethane	13.0
Urea-melamine	7.1
Nylon	1.8

These are indeed trivial amounts. Even if all the nitrogen in the polyurethane, for example, were converted to NO_2 and emitted, the total would only be 1200 tons/yr. This can be compared to the total incinerator emissions of 16,780 tons of nitrogen oxides, or the United States total of 22,800,000 tons/yr.[30]

Effect of Plastics on Other Emissions

Several other air pollutants could be formed by incineration of special plastics, or as a result of some additive in the plastic. Thus HBr might result from bromine compounds added as flame retardants. Acrylonitrile materials may form some HCN. However, the amounts of these materials would necessarily be small, and could only be a problem if a large quantity of one such plastic were being burned at one time, and stack emissions were swept down to ground level fast enough to create a toxic concentration.

SECTION V

LAND DISPOSAL OF MUNICIPAL REFUSE CONTAINING PLASTICS

Description of Methods of Disposal

As mentioned earlier land disposal of municipal refuse takes place by either sanitary landfilling or open dumping, the latter category including improper (or unsanitary) landfilling. In this section a brief description of the operations involved in each category will be given.

Sanitary Landfills

According to the American Society of Civil Engineers sanitary landfilling is "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary".[8]

There are two methods of landfilling solid waste.[18] The first is designated as "area method" while the second is called the "trench method".

In the area method a bulldozer spreads the refuse on the ground surface (or against the working face). The refuse is then compacted and a scraper is used to haul earth cover material for spreading over the day's operation. This usually is called a "cell". The area method of landfilling is best suited to flat or gently sloping lands, quarries, ravines, strip mines and natural depressions. A variation on the area method employs cover material obtained by excavation of the area directly in front of the working face.

Where the water table is relatively low the "trench" method could be used. Here the refuse is deposited in pre-excavated trenches

and cover material is obtained from spoil banks generated in the excavation process.

In both methods the refuse is compacted and at least a 1-foot thick earth cover surrounds the refuse on all sides. A 3-foot earth cover is spread on top of the highest cell in the fill or in any given "lift".

The "cell" construction provides adequate protection against the spreading of fire and infestation with insects or rodents. Provisions are usually made for the collection of leachate and venting of gases generated within the landfill as a result of biological activity.

Open Dumps

As the name implies, disposal by this method simply involves dumping the refuse on land without any effort toward altering or modifying its appearance or nature. Open dumping is widely practiced because of its immediate expediency and low cost.

Open dumping usually occurs in natural depressions, flat lands and, in general, on terrain that is sufficiently distant from centers of collection yet close enough to those centers to minimize hauling costs. A few years ago EPA launched a program aimed at closing 5000 of these open dumps. It is now fully recognized that this method of disposal is clearly inadequate as it poses a number of health hazards and presents air and water pollution problems.

In some instances refuse in open dumps has been covered after long periods of exposure. The covering process should not in this case be construed as sanitary landfilling as many of the safeguards incorporated in the latter are lacking in this simple covering operation.

The Contribution of Land Disposal of Plastics to Environmental Pollution

Environmental pollution concerns the effects of a given operation or action on the air, water, and land environments in addition to unusual noise problems resulting therefrom. It should be stated at this point that plastics in the solid waste stream act as inert materials and

in and of themselves do not directly contribute any pollutants except in the case of their burning in the open. However, because of the 5 volume percent contribution of plastics to solid waste their presence will possibly cause an increase in the total amount of water and some air pollutants emitted per unit time. This is simply because the putrescible components of solid waste will be exposed to larger amounts of water through runoff, infiltration, and percolation. It is estimated that 5 percent more water will contact the putrescible components because of the presence of plastics in landfills and dumps. This does not take into account the "dilution" effect that plastics may have on the putrescible components.

In the case of open burning the plastic contribution is obviously gravimetric in that it depends on the weight percentage of plastics in the refuse.

Air Pollution Impact from Land Disposal of Plastics

Air pollution from land disposal of municipal refuse results from (1) open burning, (2) gases generated from the biological degradation of the putrescible components of refuse in open dumping, and (3) gases generated in the biological degradation of the putrescible components of landfilled refuse.

Open burning of refuse may be either accidental or deliberate. The purpose of deliberate burning is the reduction of the volume of solid waste. It is estimated that annually 52.5 million tons of refuse are disposed of in this manner. The emission rates for the various pollutants together with the amounts thereof that are annually emitted, are given in Table 11. The emission of smoke and odiferous gases are particularly offensive and cause adverse public opinion as discussed later.

A number of gaseous species are generated from the biological degradation of open dumped and sanitary landfilled refuse. The main species are carbon dioxide, methane, water vapor and nitrogen. Small amounts of hydrogen, and hydrogen sulfide may also be generated. None of the main gaseous species are classified as toxic. However, methane

TABLE 11. THE CONTRIBUTION OF PLASTICS EMISSIONS FROM OPEN BURNING OF REFUSE

Pollutant	Emission Rates, lb/ton[a]		Annual Emissions Open Burning of Plastics in thousands of tons	Percent of Total Annual Emissions from Incinerators
	Combustibles in Refuse	Plastics		
Particulates	19.8	19.8[b]	13.6	11
SO_x	1.2	--	--	--
CO	105	105[b]	72.4	25
Hydrocarbons as (CH_4)	37	37[b]	25.5	200
NO_x	7.4	7.4[c]	5.1	30
HCl	Not known	95[d]	65.5	130

(a) This assumes that the combustible components of municipal refuse are about 81 percent. Source: References 17 and 19.
(b) For CO and hydrocarbons the combustible materials in municipal refuse are sufficiently similar in chemical composition to plastics that using the same emission factors is probably warranted.
(c) While some plastics (like urea-melamine) contain nitrogen, the contribution to the total NO_x emission will probably be negligible since in open burning a reducing atmosphere probably is prevalent.
(d) The HCl emission factor from open burning was computed by assuming that all chlorine in PVC is converted to HCl.

Note: Source: Reference 19 unless otherwise indicated.

forms explosive mixtures with air in concentrations from 5 to 15 percent by volume. While hydrogen sulfide has not been found in sufficiently high concentrations as to be toxic, it is extremely odoriferous and its noxious odor could be detected at the 1 part per billion level in air.

There is a dearth of information as regards gas generation in open dumps although an estimated 97.5 million tons of refuse were disposed of in this manner in 1973. It has been assumed however that 50 percent of the putrescible components of the open dumped refuse decompose anaerobically while the other 50 percent (the top of the pile) perhaps decompose aerobically. Assuming that the putrescible components of refuse are largely fats and carbohydrates then methane and carbon dioxide will be the major products of anearobic decomposition while carbon dioxide and water vapor will be the major products of aerobic degradation.

Under the anaerobic conditions prevailing in a sanitary landfill, the complex organic compounds (carbohydrates, proteins and fats) are first broken down into organic acids by the action of ubiquitous heterotrophic organisms that are present in the soil. The organic acids are then further broken down into gaseous products by the so-called methanobacteria.[11] The patterns of gas production are given in Figure 2 and typical gas compositions are given in Table 12.

The presence of plastics in a landfill will increase its volume by about 5 percent as previously mentioned. This volume increase will also imply a surface area increase of about the same magnitude. Consequently the putrescible components of solid waste will effectively "see" approximately 5 percent more moisture as a result of the infiltration of surface and rain water into the body of the landfill.

Anderson and Callinan[21] theoretically predicted that a pound of refuse could potentially produce 6.6 cu ft of gas. However, in an experimental study by Coe[20] it was found that anaerobic gas production ranged between 0.035 and 0.21 cu ft of gas per pound of dry and saturated refuse respectively. Assuming an average of 0.12 cu ft of gas per pound and a 5 percent contribution due to the presence of plastics as explained

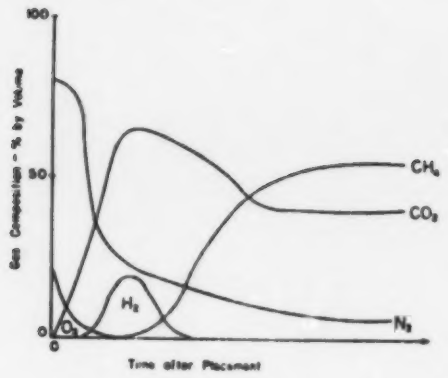

FIGURE 2. PATTERNS OF GAS PRODUCTION IN A TYPICAL SANITARY LANDFILL. Source: Ref. 11

TABLE 12. COMPOSITION OF TYPICAL LANDFILL GAS AS A FUNCTION OF TIME. Source: Ref. 18

Time interval since start of cell completion (months)	Average percent by volume		
	H_2	CO_2	CH_4
0-3	5.2	88	5
3-6	3.8	76	21
6-12	0.4	65	29
12-18	1.1	52	40
18-24	0.4	53	47
24-30	0.2	52	48
30-36	1.3	46	51
36-42	0.9	50	47
42-48	0.4	51	48

above, their potential contribution to gas production will then amount to about 0.006 cu-ft of gas per pound of refuse. It must be stressed at this point that the presence of plastics probably accelerates the generation of landfill gases and does not affect their cumulative production per unit volume of refuse. Given these assmumptions, the presence of plastics could potentially cause the generation of 2200 tons of methane and 13,000 tons of carbon dioxide per year assuming a gas composition of 65 percent CO_2 and 29 percent methane.[18] Using data reported by Coe[20] approximately 600 tons of carbon dioxide per year may diffuse into the ground water, while 12,300 tons per year will be eventually released to the atmosphere.

Gases generated in a landfill have been known to be detrimental to all vegetation in the vicinity thereof presumably as a result of the displacement of oxygen in the root zone. They have also been known to cause explosions and fires (in cases of inadequate venting) through migration and entrapment in spaces underlying neighboring structures. Carbon dioxide which dissolves in ground waters is known to be detrimental to their quality.

For open dumped refuse it will be assumed that adequate ventilation exists and no serious problems will result from the main gaseous species mentioned earlier. Odor problems resulting from open dumps are aesthetic in nature and will be discussed later in this report.

The Water Pollution Impact from Land Disposal of Plastics

Land disposal of municipal refuse could pose serious water pollution problems without proper safeguards. In the case of sanitary landfilling such safeguards could be applied while in open dumping it seems that no attempts have been made to contain or prevent potential water pollution.

In landfills as well as in open dumps variable amounts of highly polluted odoriferous waters (called leachate) are generated. The source of water is infiltration in the case of sanitary landfills and surface

runoff of precipitation in the case of open dumps. Of course, these are important elements of the water cycle which vary with location and topography. In what follows an attempt will be made to assess an order of magnitude of the water pollution problem (attributed to plastics disposal) from average data.

Many studies of the characteristics and amounts of leachates from sanitary landfills have been conducted. Fanoni[11] reviewed the experimental data available and Thornton and Blanc[15] presented "average" values for the characteristics of leachates from sanitary landfills. Fanoni[11] and Stone et al.[22] pointed out qualitative differences between leachates obtained from refuse decomposition under both aerobic and anaerobic conditions. In general, it can be stated that leachates resulting from aerobic decomposition are lower in BOD content (about 5 times lower) than their anaerobic counterparts. Also both organic and inorganic species present in the former are in a higher state of oxidation than in the latter.

The characteristics of the leachate resulting from landfills are given in Table 13.

TABLE 13. CHARACTERISTICS OF LEACHATE FROM SANITARY LANDFILLS

Constituent	Minimum Value	Average Value	Maximum Value
pH	5.60	6.55	7.63
$CaCO_3$	650	3,633	8,120
Alkalinity ($CaCO_3$)	730	4,629	9,520
Calcium	115	1,047	2,570
Magnesium	64	181	410
Sodium	85	940	1,805
Potassium	28	959	1,860
Total Iron	6	110	305
Ferrous Iron	2	24	93
Chloride	96	1,814	2,350
Sulfate	39	248	730
Inorganic phosphate	0.2	7	29
Organic Nitrogen	2	163	550
Ammonia Nitrogen	0.2	437	845
BOD	81	10,850	33,100

Note: All date with the exception of pH values are in milligrams per liter.

Source: Ref 15.

In attempting to assess the impact of the presence of plastics in open dumps and sanitary landfills on the water quality of ground and surface waters, the annual BOD loading from each source will be used as a criterion. While it is recognized that other criteria of water quality (such as pH, alkalinity, total dissolved solids, total solids, COD, etc.) may be of equal importance, the lack of data on the qualities and quantities of water from open dumps suggested the use of BOD as a criterion because it is the easiest to estimate. It is of course implied that most or all of the constituents of leachates obtained from sanitary landfills will be associated with the BOD in various concentrations depending on the mode of decomposition prevailing therein and the rates of leaching. It is estimated that landfills contribute 46,500 tons BOD per year to ground, and eventually surface waters, of which 5 percent or 2,300 tons may be leached as a result of the presence of 5 volume percent plastics component of the solid waste. This assumes that 1.85×10^{-3} tons BOD are leached from each ton of landfilled refuse annually[15] and that water percolating through the landfill will carry this BOD loading along with the dissolved solids, the alkalinity, and the nitrogenous materials.

Open dumping (without burning) of refuse will probably contribute a total BOD loading of 150,000 tons of BOD annually of which 7,500 tons may be attributed to the presence of plastics. The assumptions made in arriving at this loading were (1) 50 percent of the decomposition occurred anaerobically (2) the level of BOD available for leaching from aerobic decomposition is 25 percent that from anerobic decomposition and (3) the BOD available for leaching as a result of anerobic decomposition was about 2.5×10^{-3} ton BOD per ton of refuse.

Open dumped (but burned) refuse could contribute one-tenth to one hundredth the BOD loading of open dumped but unburned refuse.[11] While the leachate from this source may contain large amounts of dissolved solids (of the order of 8000 mg. per liter) and a high level of COD (about 1300), its relative contribution to water pollution may be neglected on the basis of the assumed BOD criterion.

To put the water pollution estimates in their true perspective a relatively well known basis of comparison was established. This basis

of comparison (or base case) is the BOD loading in the raw sanitary sewage of a city of 1 million. A typical water use rate and BOD concentration were assumed. These were 70 gallons per capita per day and 250 mg BOD per liter. The resultant loading is about 27,000 tons of BOD per year. The presence of plastics in open dumps (without burning) seems to contribute about 28 percent of the base case while their presence in sanitary landfills seems to contribute about 6 percent of the base case.

Water pollution control in sanitary landfills is currently practiced and is a fairly well developed technology. Control of polluted water from open dumps could be employed in principle but it is doubtful whether it is or has been at all practiced.

Land Impacts of Plastics Disposal

The disposal of plastics on land results in an annual commitment thereof amounting to an estimated 52 acres in sanitary landfilling and 950 acres in open dumping (without burning). Plastics were not assumed to contribute materially to land commitments in open burning. The estimates were based on a density of 900 lb per cu yd and an average height of 30 ft for sanitary landfills. For open dumps a density of 320 lb per cu yd and a height of 20 feet were assumed.

It is difficult to accurately assess the land area commitment as it is very sensitive to refuse density and height to which refuse is piled. The assumed average 30 foot height for sanitary landfills could be higher or lower depending on the nature of the site. For example, the Kansas City landfill site will have an average height of about 17 feet.[10] Were this the average used in the estimate a 90 percent increase in the estimate would have occurred. For open dumping the uncertainties are even greater. Here the heights may vary widely and refuse densities could range between 450[8] and 320 lb per cu yd. While the latter density was used to obtain a conservative estimate using the former would have yielded a 30 percent reduction in the annual land commitment for open dumping.

Poorly vegetated top soil in sanitary landfills will contribute to the 4 billion tons of sediment that washed into the surface waters of the continental United States in 1971 by erosion.[23] Erosion of poorly vegetated land surface has been put somewhere between 10 and 30 tons per acre per year.[23] However, the contribution of sanitary landfilling to soil erosion may be considered negligible because of the relatively smaller areas affected.

In the absence of proper controls sanitary landfills and subsequently landfilled open dumps restrict the uses to which the land may be subjected. This is primarily attributable to land settlement and decomposition gases. The magnitude of settlement could be as high as 10 feet per year (during the first year) and as low as 2 feet depending on the amount of precipitation and nature of the decomposing refuse.[18] Because plastics do not decompose in a landfill, the forms in which they are present will affect the settling characteristics thereof. In addition to producing uneven settling they will affect the bearing capacity of the soil. The incremental effect of plastics disposal on the subsequent uses of a landfill cannot be assessed accurately at this time. However, in as much as plastics do contribute an estimated 5 percent to the volume and, hence, the area of a landfill, so will be their minimum contribution to the consequences of landfilling. Subsequent uses for landfill sites include those that are agricultural and recreational in nature. Construction on or in the vicinity of landfill sites can only be undertaken by the application of proper controls to safeguard against the detrimental effects of settlement and decomposition gas movement.

The impact of plastics disposal in landfills can be assessed in an economic fashion. Plastics will bear 5 percent of the cost of control technology employed in bringing the affected land to its desired end use (highway, building, recreational, etc.).

Noise Impacts of Plastics Disposal

Noise affects both man and animals. Efforts aimed at understanding its effect on humans are currently being intensified and many aspects of those effects are becoming fairly well known at least qualitatively. Case and Ventre[24] have given an excellent review of the various aspects of the noise problem and its impact on man.

It seems that continuous and indefinite exposure to noise levels of 80 dB (decibels) are not detrimental to humans. Noise exposure levels of 85 dB for 8 hours per day are not detrimental. The rule of thumb[25] is that a 5 dB increase (above 85 dB) in the noise level decreases the permissible exposure time per day by 50 percent.

While hearing loss is "the most significant physical disability in the U.S."[24], it is not the only detrimental effect of noise. Medical research has found that stress resulting from exposure to "continuous" and "sudden" noise may cause such problems as cardiovascular disease, fatigue (due to loss of sleep), nausea, headaches and respiratory irregularities. Noise further interferes with speech and mental concentration thus contributing to loss in productivity.

The effects of noise on animals are not as well known. Generally, it tends to displace land animals and birds from their natural habitats wherever it is applied therein. It has been shown that animals inhabiting relatively "quiet" environments, (such as forests and the countryside) overexert when fleeing ground vehicles (such as snowmobiles) and low-flying aircraft.

In many cities the ambient traffic noise levels may reach 90 dB and are increasing at the rate of 1 dB per year.[24] It is not clear at this time how much the collection of refuse contributes to the urban noise problem. But regardless of magnitude, plastics disposal will contribute in amounts equal to their volume percentage to the impact. Some of the "costs" associated with noise are, (1) depression of property values,

(2) costs of sound insulation, (3) reduction in efficiency and increases in social conflict, (4) cost of anticipated litigation, and (5) costs of physical damage (hearing loss, cardiovascular disease, etc.).

Noise generated at the sites of refuse disposal (landfills and open dumps) is of course associated with the equipment used therein. Table 14 shows the noise emitted from representative machines used in solid waste disposal. Inspection of the noise levels at 50 and 1000 ft in Table 14 sugests that landfill and open dump operations do not pose serious noise problems to potential residents in the vicinity of the sites. Also local zoning laws will perhaps mitigate the impact of this source. Serious health problems may be incurred by the sanitation workers in the immediate vicinity of the machines. However it is well known that workers in municipal refuse collection and disposal suffer from the higest occurrence of injury and disease per man-hour known in industry.[13] Under proper control, noise may be the most inconsequential source of injury or sickness to the workers relative to other sources.

Ecological Impacts of Land Disposal of Plastics

The ecological impacts are concerned with effects of land disposal on the terrestrial and aquatic biota. These effects can be discussed only qualitatively at this time.

Leachates from sanitary landfills and open dumps reaching stretches of natural surface waters (streams, rivers, and lakes) may be sufficiently high in BOD and other pollutants as to cause fishkills and the destruction of other aquatic life therein. In the case of sanitary landfills, leachate control and treatment may alleviate this problem. The contribution of plastics to leachate generation in sanitary landfills and open dumps has been discussed earlier.

Decomposition gas movement in sanitary landfills has been known to cause the destruction of plant life in their immediate vicinity. This presumably happens as a result of the exclusion of oxygen from the root zone by methane and carbon dioxide.

TABLE 14 . NOISE LEVELS FROM TYPICAL EQUIPMENT USED IN MUNICIPAL REFUSE DISPOSAL[a]

Piece of Equipment	Estimated Horsepower	Capacity	Noise Level, in dB, at Various Distances, in ft, from Source		
			Immediate Vicinity	50 ft	1000 ft
Mobile Packer	150	18 cu yd	90-110[b]	72-83	65
Crawler Dozer	100-130	--	90-110	65-80[c]	38-53
Crawler Loader	150-190	3 cu yd per bucket	90-110	72-83[c]	45-56
Drag Line	--	3 cu yd per bucket	90-110	75-88[c]	68-61

(a) Source: C. W. Rodman[25].
(b) Based on noise of a diesel engine at 3 ft.
(c) Source: "Noise from Construction Equipment and Operations, Building Equipment and Home Appliances", U.S. EPA, PB 206-17, Washington, D.C. December 1971.

The mere encroachment upon the land environment will displace terrestrial biota previously inhabiting the dumping or landfill sites. Species that are incapable of adapting to the displacement will become endangered, and perhaps extinct. In cases of open dumping the sites become infested with rodents and insects and, in general, possible disease vectors, such that a distinct possibility exists that wildlife in the vicinity will become infected with a host of dangerous diseases. The contribution of plastics to this impact is again in direct proportion to their volume percentage in the refuse.

Aesthetic Impacts of Land Disposal of Plastics

It is generally agreed that litter and open dumping of refuse are objectionable practices that mar the appearance of the landscape and cause odors. The consequences of this are feelings of annoyance and displeasure in man. Because plastics in solid waste are essentially non-degradable and have a low bulk density, it is possible to see objects made therefrom blowing in the air or floating in natural surface waters.

However, because the use of plastics as soft drink and alcoholic beverage containers is not currently significant[9] they do not seem to be a significant component in the litter problem. Available data[28] indicate that the plastics contribution to the litter problem is about 5 to 6 percent by volume.

The encroachment of open dumping upon the wilderness may reduce, in number and acreage, the areas of scenic beauty and recreation in the vicinity of urban centers. This will undoubtedly intensify psychologically, and, perhaps, physiologically stressful conditions in those centers. The contribution of plastics to this impact is in direct relationship to their volumetric presence in the refuse.

Properly operated sanitary landfills have minimal aesthetic impacts. It seems that odors, blowing papers, and plastic objects can be adequately controlled. Furthermore, in many operations attempts are made to conceal the refuse from neighbors or casual observers of the site.

Human Interest Factors in Relation to the Land Disposal of Plastics

The human interest factors of most significance in connection with solid waste, and hence, plastics are: (1) the human health-related factors, (2) the social factors, and (3) the economic factors. The health factors are the most serious since they in turn affect all others.

Health Effects

The effects of noise on human health and the environment have been discussed earlier. In what follows an attempt will be made to relate the environmental and ecological impacts of land disposal of solid wastes to already known adverse impacts on human health and well-being.

While it is currently recognized that improper solid waste disposal (open dumping) poses serious threats to health, the problem is of such complexity as to defy quantitative treatment. The quantitative treatment would probably involve the determination of cost(s) to society of injury, sickness, or death that are directly attributable to waste disposal.

Sanitary landfills pose a minimal health impact when properly operated. In the absence of proper control therein leachates may contaminate (with metal ions, pathogens, and other pollutants) well waters in rural and suburban areas and will increase the contaminant loading to ground and surface water supplies that will eventually be used for drinking and recreational purposes. Heavy metals (such as lead, zinc, and cadmium) are poisonous. Even iron in relatively large doses is reportedly detrimental to the liver and the urinogenital system. Landfill gases, if not properly vented, could cause asphyxiation and serious explosions in neighboring residential areas.

Open dumping poses a very serious threat to human health. Its relationship to disease potentials in humans has been reviewed by Hanks[26]. Open dumps provide a food source and harborage for rodents, insects, and,

in general, disease vectors (or disease carriers). While this in and of itself is a serious consequence, the mere encroachment of open dumps upon land which hitherto had been a wilderness poses the threat of increased interaction between the wild and "domestic" rodents thus spreading the "reservoir" of disease. On this Hanks[26] may be quoted:

> "The ultimate threat of epidemic plague comes from commensal rat populations, but the basic threat in the United States exists in the wild rodent reservoir. The first essential element for a human plague epidemic in this country--contact between commensal rats and wild rodents--is being satisfied by encroachment of urban settlements on wild areas and the use of such areas as dumps for solid wastes. In addition, the fact that more and more Americans invade wilderness areas every year, exposing themselves to sylvatic plague and producing tons of litter and garbage for which they assume no responsibility for proper disposal, is of considerable importance. This can bring about avenues of transmission made important by sheer numbers of potential victims, a growing population of wild rodents attracted to (and nourished by) such wastes, and the increasing probability of involvement of hitchhiking domestic rodents."

The land disposal of plastics merely causes an increase in the acreage of affected areas and participates in proportion to its volume, in the consequences of encrocahment upon the wilderness.

Air pollution resulting from the open burning of refuse may cause the health hazards associated with high ambient levels of pollutant concentrations in areas adjacent to the dumping sites. Smoke and particulate matter together with odors are highly unaesthetic and produce adverse reactions in man.

Socioeconomic Factors

There is little doubt that the use of plastics in packaging and other uses has enhanced the quality of life in the United States. The versatile properties of plastics (light-weight, strength, transparency,

ease of fabrication and relative low cost) have encouraged their incorporation into a variety of products used for the benefit of man. However some of the properties of plastic products (such as nonbiodegradability and low bulk density) have raised serious questions as to their suitability for proper land disposal. State and local legislation was passed as a result (in relatively few locales) that tended to inhibit the use of plastics. Litigation and court action ensued in these cases.[42] It can be stated at this point that current legislation affecting the disposal of plastics is in a state of flux since many aspects of the issue remain unresolved. However, if special interests and gaps in the state of knowledge continue to interfere with the correction of deficiencies in solid waste management, serious changes in life styles and adverse effects on the quality of life will result.

The land disposal of plastics carries a number of socio-economic implications. These are mainly related to (1) cost of disposal to the community, (2) depletion of natural resources, and (3) how (1) and (2) will affect the life styles of plastics consumers.

The costs of land disposal of plastic are directly proportional to their volumetric contribution thereto. The projected increase in the weight percentage of plastics in refuse will imply an increase in volume percentage. This will increase the costs of disposal per ton of refuse. The consumer will, of course, eventually pay for this increase.

The open dumping and landfilling of plastics represents a loss in material and energy resources. From an energy point of view this disposal represents about 0.5 percent of the 1974 total utility energy requirements. On the materials side, the resins used in the fabrication of plastic consumer goods are currently made from petroleum based products. Of course, petroleum is a nonrenewable resource and the land disposal of

plastics contributes in a very small way to its eventual depletion. Processing the resins into finished products will result in a fourfold enhancement of their value.[27] Efficient recycling of plastics that are currently disposed of on land will perhaps result in a cost saving in the manufacture of end products therefrom. To encourage recycling a number of schemes are presently under consideration.[27] Some of these schemes involve (1) the taxation of virgin materials (resins and monomers), (2) incentive payments made to reprocessors, and (3) taxes on nonrecycled products. Any or all of the schemes employed will necessarily have to take into consideration the state of the art of recycling technology.

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